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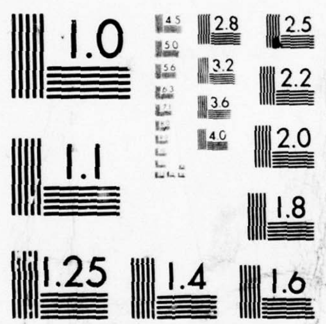

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Research and Development Technical Report

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LINEAR 1 kW MULTITONE TROPOSCATTER TWT

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3100 West Lomita Boulevard
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August 1978

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Prepared For: Electronics Technology and Devices Laboratory

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FORT MONMOUTH, NEW JERSEY 07703

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This report covers the second triannual effort of a Research and Development program to design, construct, and test an advanced, high efficiency traveling-wave tube designed to amplify multiple signals while minimizing any mixing products which result from non-linear operation. The tube will be operated in the linear region below saturation; tube efficiency will be enhanced by means of a four stage depressed collector.

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20. During the report period the scaled electron gun was constructed and evaluated in the demountable beam analyzer. The detail mechanical design for the gun to be used in the tube was completed. Parts were ordered.

Phase shift measurements of the RF circuit were completed. Circuit parts for the tube were ordered.

The mechanical design of the four stage collector was continued. Thermal analysis led to a change in the electrode configuration to handle the high power densities.

Design of the overall packaging was started.

PURPOSE

The purpose of this program is to design, construct, and test an advanced high efficiency traveling-wave tube in accordance with U.S. Army Electronics Command, Beam, Plasma and Display Technical Area Guidelines "MW-114 for the Linear 1 kW Multitone Troposcatter Traveling Wave Tube". dated 20 October 1976. This tube will be designed to amplify multiple signals while minimizing any mixing products which result from non-linear operation. It will operate at a power output of 1.0 kW CW with a gain of 40 dB over the 4.4 to 5.0 GHz frequency band. It will be operated in the linear region below saturation. Overall tube efficiency will be enhanced by means of a multiple stage depressed collector. The tube will use a coupled-cavity interaction circuit with integral permanent magnet beam focusing. Air cooling is an objective.

The program calls for the delivery of one exploratory developmental model representative of the work accomplished under the development effort. The length of the program is twelve months.

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1.0 INTRODUCTION

The basic objective of the present program is to demonstrate an optimum traveling-wave tube (TWT) design for applications in tactical tropo-scatter communications systems. The design of this tube will be based on the data presented in the Research and Development Technical Report ECOM-75-1283-F. The primary design concept is to operate the tube below saturation in order to achieve the low intermodulation (IM) requirements. To achieve the required performance characteristics the tube will be operated approximately 6 to 7 dB below saturation. At the rated power of 1.0 kW minimum, the basic efficiency of the tube will be approximately 4 percent. To improve the overall efficiency of the tube, a four-stage depressed collector will be used to recover most of the kinetic energy in the spent beam. The original design study indicated that the overall efficiency can be increased to a minimum of 25 percent by using this technique.

The specification for the multitone troposcatter TWT is presented in Table I.

Periodic permanent magnet (PPM) focusing of the electron beam and air cooling are objectives of the tube design because the overall efficiency will be greater if PPM focusing is used in place of conventional sole-noid focusing with the attendant solenoid power supply and air cooling will make the tube more compatible with existing troposcatter transmitters. Therefore, these features are being used for the multitone tube.

The theoretical electrical characteristics of the tube were described in detail in the earlier report, ECOM-75-1283-F. The purpose of the present program is to construct a tube having the previously determined

TABLE 1

SPECIFICATION FOR MULTITONE TROPOSCATTER TWT 673H

Electrical Requirements:	
Frequency Range	4.4 - 5.0 GHz (Min)
Power Output CW	1 kW (Min)
Gain	40 dB (Min)
Instantaneous Bandwidth (-1 dB)	15 MHz (Min)
Beam Voltage	-26 kV (Max)
Beam Current	1.5 A (Max)
Efficiency (Note 1)	25% (Min)
Intermodulation (Note 2)	-20 dBC
Output Load VSWR	1.5:1 Max
Focusing	PPM (Objective)
Life	10,000 Hrs. (Objective)
Mechanical/Environmental:	
Size	To Be Determined (TBD)
Weight	To Be Determined (TBD)
Cooling	Air (Objective)
RF Input Connector	Type N Coax
RF Output Connector	WR-187 Waveguide/UG-149/Flange
Altitude (Operating)	3,100 Meters
Ambient Temperature (Operating)	-50°C to 55°C
Mounting (Operating)	0 to 15° from Vertical
Shock (Non-operating)	50 G, 1 msec
Vibration (Non-operating)	5 to 55 Hz 1.02 cm Amplitude 5 ± 0.5 Minutes

Note:

1. The overall TWT efficiency is defined as:
RF output power divided by the sum of beam input power, cooling power, focusing power, and heater power. The tube shall be capable of meeting the efficiency specified under conditions where the IM products are within the specified limits with 4 to 16 signals applied to the input.

2. The intermodulation products requirement will be met over any 15 MHz band in the 4.4 GHz to 5 GHz frequency range. The 15 MHz band will be divided into sixteen adjacent equal bandwidth channels. Anywhere from 4 to 16 of the channels will be occupied by carriers. The total intermodulation power in any occupied channel shall be 20 dB below the carrier in that channel. The carrier output power of all the occupied channels shall total 1 kW.

design parameters and measure its operating performance. This effort consists chiefly of the following areas:

1. An electron gun will be scaled to the required beam size, area convergence, and perveance and mounted in an existing isolated anode support structure.

2. The RF intereaction circuit and integral PPM focusing structure will be designed. This includes determining the final circuit dimensions to give the required phase shift characteristics, providing adequate circuit loss for stability, and matching the circuit to internal sever terminations, an input coaxial coupler, and an output waveguide step transformer and window.

3. The mechanical design of the four-stage depressed collector will be accomplished, taking into account the voltage standoff and thermal dissipation requirements, using the electrode configuration that had been determined previously.

4. The overall packaging and cooling structure of the tube will be designed.

5. The experimental tube will be fabricated and tested.

During the second triannual period of the program the scaled electron gun was evaluated in the demountable beam tester, the mechanical design of the electron gun was completed, and parts for the gun to be used on the tube were ordered. The phase shift and impedance measurements were completed to establish the RF circuit configuration and circuit parts for the tube were ordered.

The mechanical design of the collector was continued. A considerable amount of effort and redesign were directed to this area as a result of the thermal calculations, which indicated that over heating and excessive mechanical stress could occur as a result of the high beam power densities.

2.0 ELECTRON GUN

The basic electrical design of the 238B electron gun was described in the first Triannual Interim report. The design parameters are summarized in Table II. During the present report period a scaled version of the gun was evaluated in the demountable beam analyzer. This gun, designated the 238A, was scaled from the 238B by a factor of 0.911 in order to obtain a scaled cathode diameter of 0.440 inch (11.18 mm), which is compatible with the analyzer test fixtures. A photograph of the test setup is shown in Figure 1.

Two versions of the 238A gun were checked differing only in cathode to anode spacing. The 238A gun number 1 had a measured perveance of 0.30 micropervs rather than the design perveance of 0.33 micropervs.

The cathode to anode spacing was then decreased by 0.010 inch. The measured perveance of this 238A gun number 2 was 0.33 micropervs. The beam minimum occurs 1.432 inches (36.37 mm) from the cathode valley. The measured $r_{1/20}$ is 0.040 inch (1.02 mm) at 10 kV. ($r_{1/20}$ is the beam radius where the current density is 1/20 the peak current density.) 10 kV is the maximum test voltage that can be used with the demountable analyzer. The predicated $r_{1/20}$ at an operating voltage of 25 kV is 0.0355 inch (0.902 mm). A plot of beam voltage versus $r_{1/20}$ is shown in Figure 2.

The final 238B gun design was obtained by scaling the dimensions of the 238A gun number 2 by 1.0977. The relevant theoretical and experimental gun parameters are summarized in Table III. ($r_{99.5}$ is the radius of the envelope containing 99.5 percent of the beam current.)

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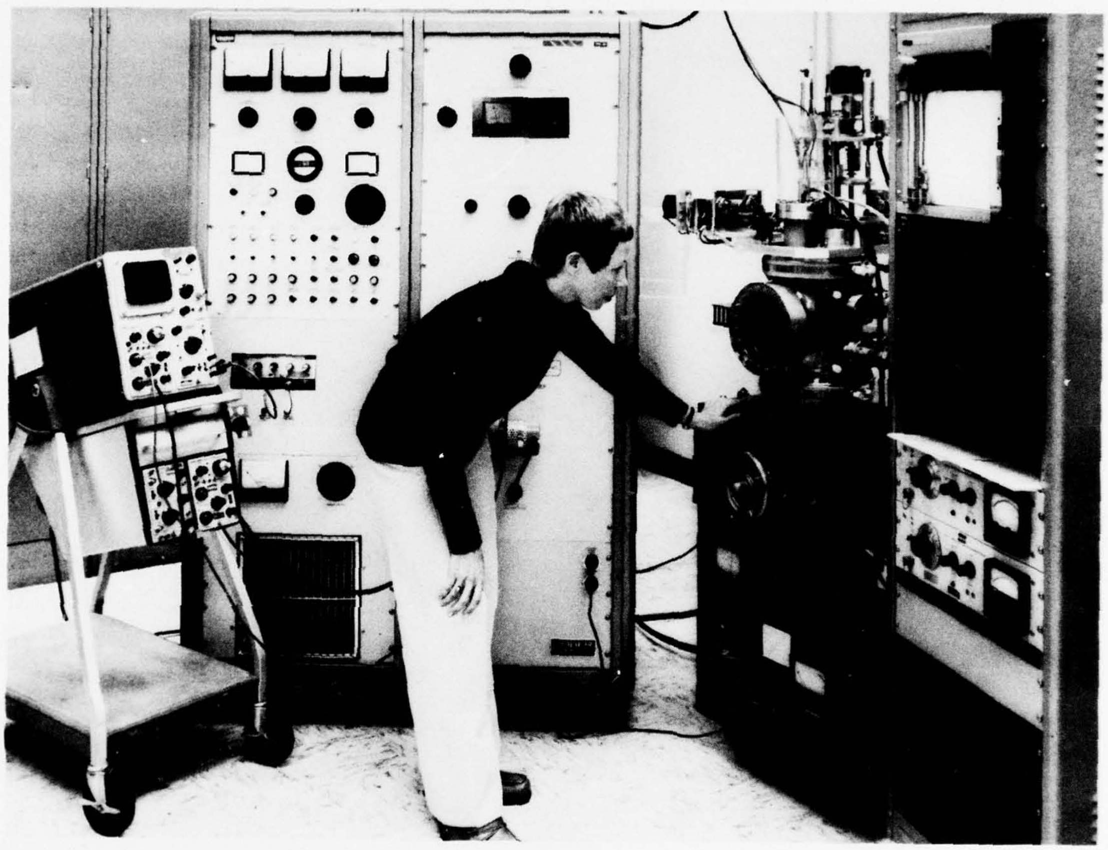


Figure 1 Electrostatic demountable beam analyzer.

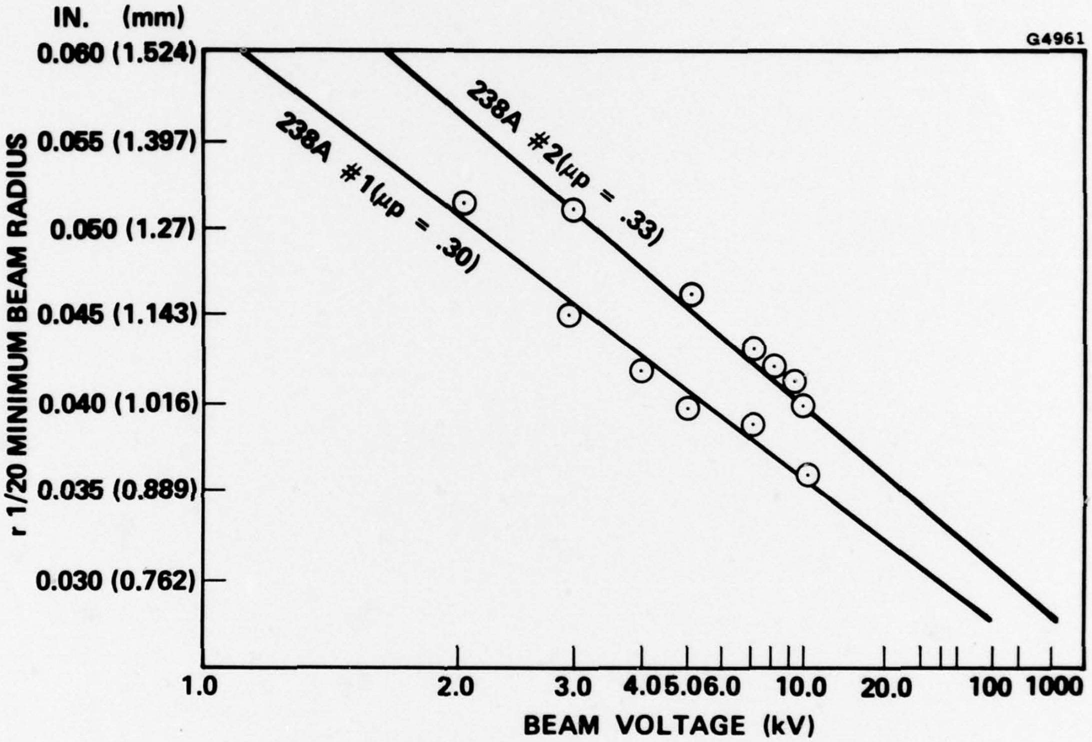


Figure 2 238A demountable guns V_b vs r 1/20.

TABLE II

238B ELECTRON GUN DESIGN PARAMETERS

Cathode Voltage	-25 kV
Cathode Current	1.3 A
Perveance	0.33×10^{-6}
Cathode Loading	1.1 A/cm^2
Nominal Beam Diameter	0.121 inch (3.07 mm)
Area Compression	16:1
Cathode Material	Impregnated tungsten
Magnetic Field	PPM
Magnetic Period	1.036 inch (26.31 mm)

The detail mechanical design of the 238B gun was completed. This involved adapting the 238B electrodes to a standard isolated anode insulator assembly with appropriate corrections to account for the differential expansions of the various support elements of the gun at operating temperature. The gun layout is shown in Figure 3.

Parts for the gun that will be used on the tube have been ordered. The design of the assembly fixtures has been started. Construction of the gun will be started in June.

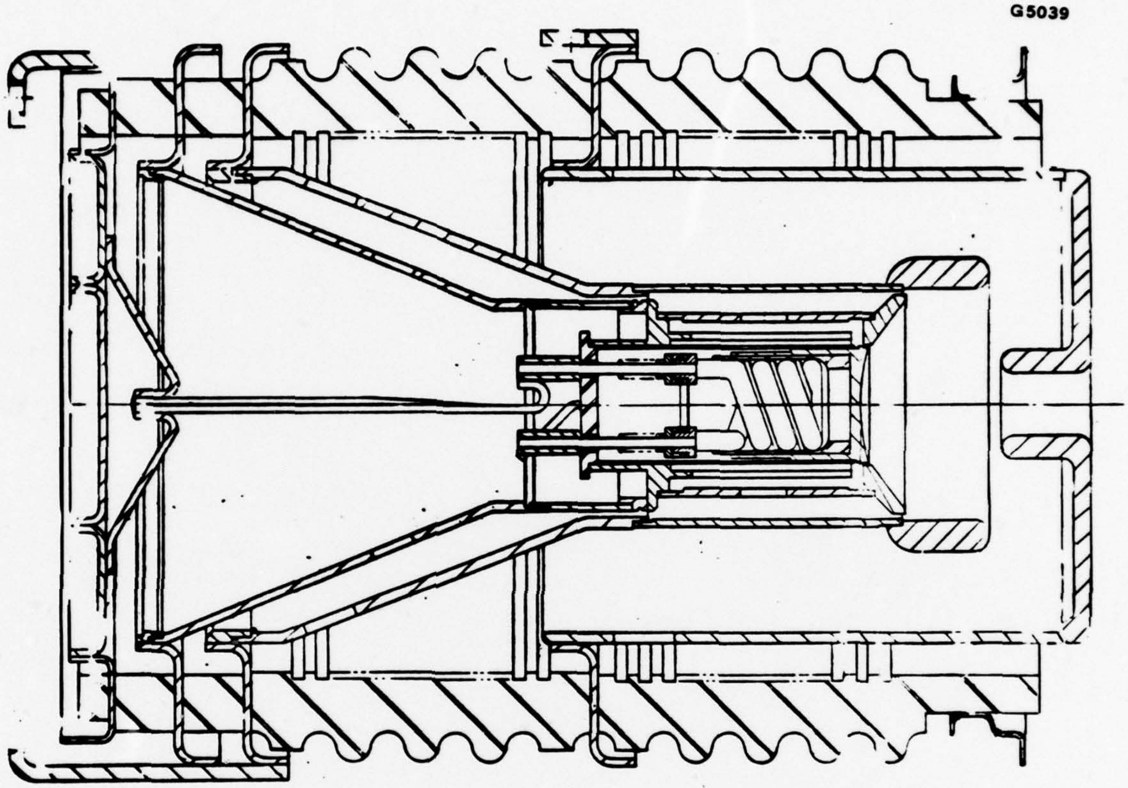


Figure 3   238B isolated anode electron gun.

TABLE III

SUMMARY OF THEORETICAL AND EXPERIMENTAL 238 GUN PARAMETERS

	238B Design	238A Number 2 Test	238B Design	238B "A" Scaled
Perveance (micropervs)	0.33	0.33	0.33	0.33
$r_{1/20}$ Electrostatic at 25 kV $\frac{\text{inch}}{\text{(mm)}}$	$\frac{0.0357}{(0.907)}$	$\frac{0.0328}{(0.833)}$	$\frac{0.0392}{(0.996)}$	$\frac{0.0360}{(0.914)}$
$r_{99.5}$ Focused at 25 kV $\frac{\text{inch}}{\text{(mm)}}$	$\frac{0.0725}{(1.842)}$	$\frac{0.0666}{(1.692)}$	$\frac{0.0796}{(2.022)}$	$\frac{0.0731}{(1.857)}$
Cathode valley to Beam Min. inches (mm)	$\frac{1.45}{(36.83)}$	$\frac{1.43}{(36.32)}$	$\frac{1.59}{(40.39)}$	$\frac{1.57}{(39.88)}$

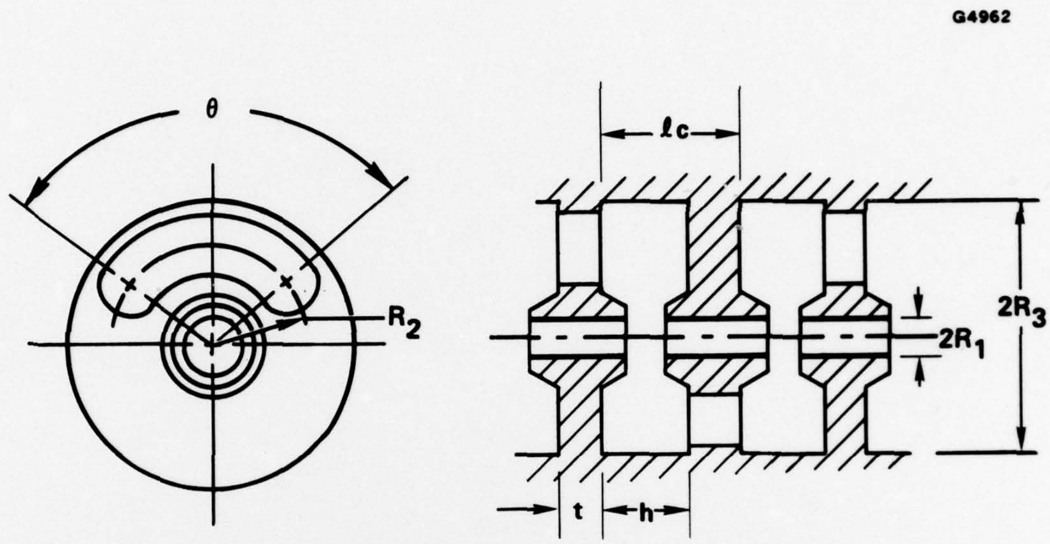
3.0 INTERACTION CIRCUIT

The basic circuit parameters for the 673H were chosen in the previous study program. During the present report period, phase shift measurements were made on experimental cold test circuit structures to obtain the exact circuit dimensions. In these measurements the drift tube ferrule gap and the size of the coupling hole are varied until the desired pass band has been obtained. Resonant loss material was included in these cold test circuits to properly simulate the actual tube circuit. (The loss material lowers the pass band by about 250 MHz). The final dimensions are shown in Figure 4.

The measured phase-vs-frequency (ω-β) characteristic for this circuit is presented in Figure 5.

Frequency perturbation measurements with a dielectric rod were made to determine the circuit interaction impedance. The small signal gain was then calculated taking into account the measured circuit impedance and electron beam characteristics. These calculations indicated that the gain will be approximately 0.1 dB per cavity higher than had been assumed in the original study. The circuit configuration has, therefore, been chosen to have 16 cavities in the driver section and 17 cavities in the output section, not including termination and matching cavities.

Cold test fixtures have been designed and fabricated. They will be used in matching the circuit to the internal sever terminations and to the external waveguide. The other circuit parts have been ordered. The pacing items are the pole pieces, which are laminations of copper and iron to improve the thermal capability. The iron-copper pole piece blanks have been brazed. They are out for final machining to the dimensions determined by the cold test measurements. They are due back in May. When they are received, the final matching and assembly of the tube circuit will be started.



$2R_1$ = 0.202 in. (5.13 mm)
R2 = 0.385 in. (9.78 mm)
$2R_3$ = 1.100 in. (27.94 mm)

ℓc = 0.518 in. (13.16 mm)
h = 0.400 in. (10.16 mm)
t = 0.118 in. (3.00 mm)
θ = 110°

Figure 4 673H cavity dimensions.

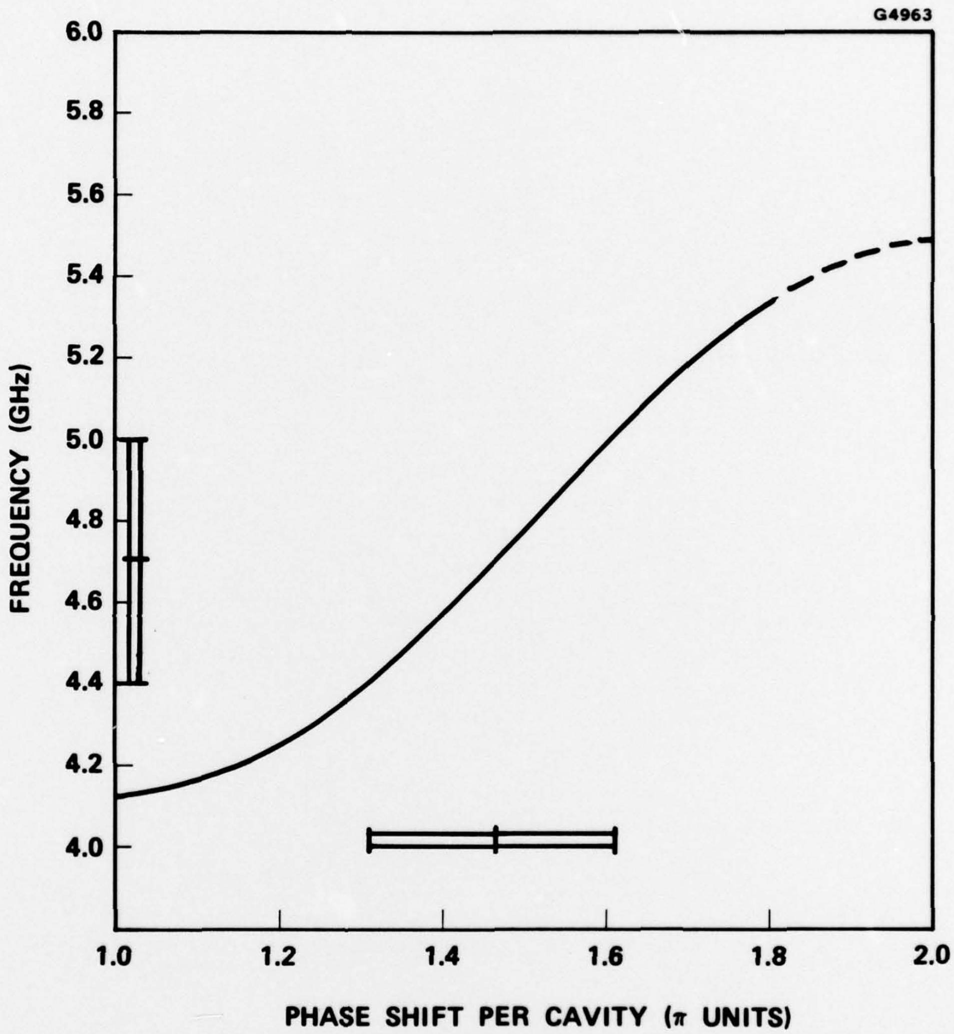


Figure 5 Measured frequency vs phase (ωβ) characteristic of interaction circuit.

4.0 COLLECTOR AND PACKAGE

As described in the last report, the four-stage depressed collector is a crucial element in achieving high overall efficiency on the 673H. The optimization of the shapes and depression voltages for each electrode was performed during the previous study program. The detail mechanical design is being done on the present program. Because of the large power dissipation and the fairly high electrode voltages required by the electrical design, the thermal and mechanical design of the collector has become the most complex and critical portion of the 673H program.

The primary design criteria for this collector is to provide the electrical standoff for the four electrodes and at the same time provide a good thermal path out to the air-cooled fins. To achieve these requirements the electrodes will be completely enclosed within a ceramic cylinder. This ceramic will provide both electrical isolation and thermal conduction in the radial direction for the collector elements. Using this technique, the electrical standoff for the collector is located within the vacuum envelope, eliminating the possibility of externally contaminating the insulator surface. The electrical connections are made through conventional high voltage feed throughs.

A preliminary layout of the initial concept of the collector design is shown in Figure 6. The individual electrodes are brazed to metalized bands on the inside of the ceramic cylinder. The electrodes are thin to relieve the stresses due to the differential thermal expansions between the copper electrodes and the alumina ceramic. The feed throughs are located in a separate weld ring located at the front of the collector near the output pole piece. This arrangement results in the shortest lengths of the connecting leads. The cooling fins could be either brazed or clamped to the outside of the metalized ceramic cylinder.

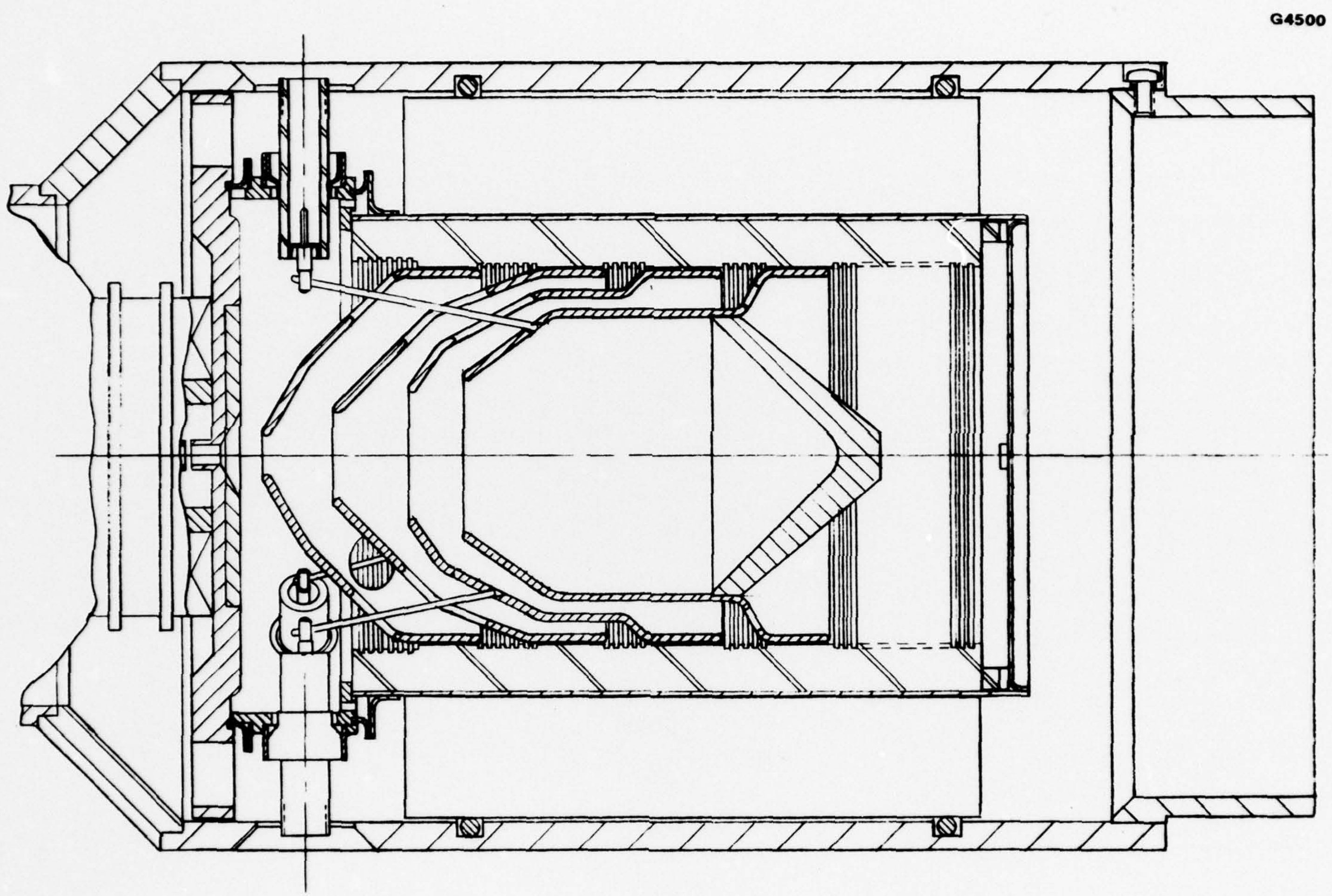


Figure 6 Layout of four-stage depressed collector for the 673H.

Drawings of detail parts were started for this initial collector configuration. However, when the thermal calculations were made for the maximum expected incident beam power, it was found that the temperature rise from the ceramic wall to the snout of the electrode would be about 1300°C, even though copper is an excellent conductor. This was entirely too high.

Therefore, the layout of the collector was modified to make the electrodes as thick as possible in the axial direction and as short as possible in the radial direction, while maintaining the shapes of the snouts of the electrodes required for good electrical performance. This necessitated running the feed throughs out at the back end of the collector. A layout of this arrangement is shown in Figure 7. Because the spacing for the leads is tighter with the feed throughs at the back, the leads will be enclosed in ceramic tubing for extra insulation. The shape of the large ceramic cylinder has been modified to accommodate this new configuration. (This did not affect the schedule appreciably because the ceramics that were on order had not yet been machined.)

It is planned that the electrodes, leads, weld flanges, and cooling fins will be attached to the ceramic insulator in a one-shot braze. The assembly fixturing is being planned accordingly.

The power distribution on the various collector electrodes will vary depending on the particular operating condition. The thermal calculations were made assuming the worst expected case for each electrode. With the present collector configuration the highest calculated electrode temperature is 428°C, which occurs on the third electrode from the output pole piece. The assumptions were an inlet air temperature of 38°C with an air flow of 400 CFM. The maximum total collector input power will be 4.8 kW with a maximum power to the third electrode 2.2 kW. The collector

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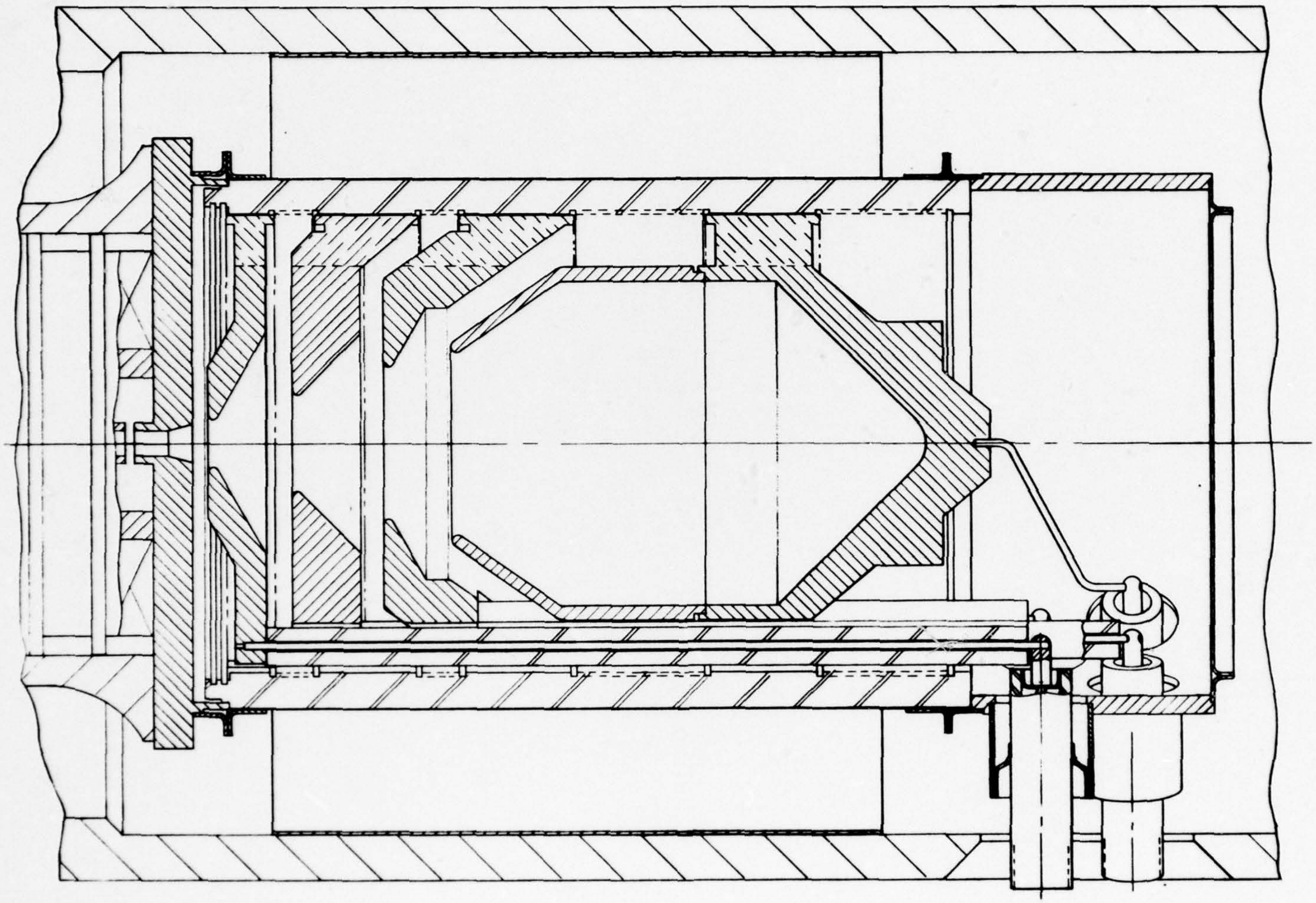

Figure 7 Schematic layout of present four-stage depressed collector for 673H.

fins will be brazed to the ceramic. The calculations take into account the fact that the air through several of the fins will be blocked by the output waveguide. Based on these results, the present design should meet the collector requirements.

The design of the overall tube package was continued. The details of the package will be finalized after the detail design of the collector has been completed.

5.0 PLANS FOR NEXT PERIOD

1. The design of the fixtures for the 238A isolated anode electron gun will be completed. They will be ordered. The gun for the tube will be fabricated, checked in the demountable beam analyzer, and put on the 673H tube.

2. The design of the four-stage collector will be completed. A sample electrode to ceramic braze will be made and evaluated. The collector parts will be ordered. The collector assembly fixtures will be designed and ordered. The collector will be fabricated and installed on the 673H tube.

3. The matching of the RF interaction circuit to the internal terminations, coaxial input line, and output waveguide will be accomplished. The circuit will be fabricated.

4. The design of the external package will be completed. Parts will be ordered.

5. The 673H tube will be assembled, processed, and tested.

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